ERS, INC.

No. 442

11/2/88

SHIPPED TO

P.O. NO.	IDENTIFICATION	TERMS
AT 161248 CN	E-PAN	NET ON ...

DESCRIPTION		UNIT PRICE	AMOUNT
18,220 lbs. crushed material			
Weight received	18,220		
Non-processible iron, etc.	520		
Weight processed	17,700	.14/lb.	$2,[illegible]
Weight recovered	8,600		
Yield	48.59%		

Can nos. 2585-2586
Box nos. 11271-11278 (8 boxes)
B/L no. MSO 3521

1988

11032354

U.S. EPA REGION IV

SDMS

POOR LEGIBILITY

PORTIONS OF THIS DOCUMENT MAY BE DIFFICULT TO VIEW DUE TO THE QUALITY OF THE ORIGINAL.

TO MAKE THE DOCUMENT READABLE, TRY ONE OR MORE OF THE FOLLOWING:

From the Displays Settings in Windows Control Panel:

1. Set the Color Quality to the highest available: 24 bit or 36 bit.
2. Increase or decrease the Screen resolution.

From the Monitor/Display Controls:

1. For dark image page, increase the brightness and decrease the contrast.
2. For light image page, decrease the brightness and increase the contrast.

** PLEASE CONTACT THE APPROPRIATE RECORDS CENTER TO VIEW THE MATERIAL**

V. 2-040506

ELTERS, INC.

INVOICE NO. 4421

DATE:

11/2/88

SHIPPED TO:

AMERICA
AL DEPT.

701

CUSTOMER P.O. NO.	IDENTIFICATION	
AT 590414 BO	MOLD LINE SCRAP	NET ON

DESCRIPTION		UNIT PRICE	
34,710 lbs. Mold Line Skimmings			
Weight received	34,710		
Non processible	------		
Weight processed	34,710	.09/lb.	$3
Weight recovered	26,194		
Yield	75.46%		
Tap nos. 5579-5581/S1655			
Sow nos. 22038-22055/S12856-S12862 (25 sows)			
B/L no. C 4572 MSO 2661			

AB

3

EETERS, INC.

INVOICE NO. 4423

DATE: 11/3/88

SHIPPED TO:

NAL CORP.
ISLAND ROAD

33909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA	NET

DESCRIPTION			UNIT PRICE	AMOUNT
32,260 lbs. Pot pads				
Weight received		32,260		
Non processible		------		
Weight processed	SMOKEY	12,200	.10/lb.	$1,
Weight processed	ROTARY	20,060	.075/lb.	$1,5
TOTAL OF INVOICE				$2,72
Weight recovered		23,444		
Yield		72.67%		
Tap nos. S1656/2587-2589				
Sow nos. 12863-12869/11279-11292 (21 sows)				
B/L no. 5036				

C

TK

PRECIATE YOUR BUSINESS

ELTERS, INC.

INVOICE NO. 4425

DATE: 11/4/88

SHIPPED TO:

L CORP.
LAND ROAD

33909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA	NET

DESCRIPTION		UNIT PRICE	AMO
16,300 lbs. Pot pads			
Weight received	16,300		
Non processible	------		
Weight processed	16,300	.075/lb.	$1
Weight recovered	11,683		
Yield	71.67%		
Tap nos. 2591-2592			
Sow nos. 11300-11310 (11 sows)			
B/L no. 571012-1			

ECIATE YOUR BUSINESS

5

...ELTERS, INC.

INVOICE NO. 4426

DATE: 11/4/88

SHIPPED TO:

...L CORP.
...HLAND ROAD
... 33909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA 10/28	NET

DESCRIPTION		UNIT PRICE	AMOUNT
22,240 lbs. Pot pads			
Weight received	22,240		
Non processible	------		
Weight processed	12,020	.10/lb.	$1[illegible].00
Weight processed	10,220	.075/lb.	$[illegible]
TOTAL OF INVOICE	------		$1[illegible]
Weight recovered	15,195		
Yield	68.32%		
Tap nos. S1657/2590			
Sow nos. 12870-12876/11293-11299 (14 sows)			
B/L no. 571019-1			

TK

...CIATE YOUR BUSINESS

6

...LTERS, INC.

INVOICE NO. 4427

DATE: 11/4/88

SHIPPED TO:

...940-0269

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	R/B	NET ON RECEIPT

DESCRIPTION		UNIT PRICE	AMOUNT
25,394 lbs. Dross, solids, etc.			
Weight received	25,394		
Non processible	------		
Weight processed	25,394	.075/lb.	$1,[illegible]
Weight recovered	13,633		
Yield	53.69%		
Tap nos. 5585-5587			
Sow nos. 22069-22081 (13 sows)			
B/L no. 7272/7284/7331			

...ATE YOUR BUSINESS

7

ERS, INC.

INVOICE NO. 4429

DATE: 11/4/88

SHIPPED TO:

CORP.
ND ROAD

33909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA 5038	NET

DESCRIPTION		UNIT PRICE	AMOUNT
18,160 lbs. Pot pads			
Weight received	18,160		
Non processible	------		
Weight processed	18,160	.10/lb.	$1[illegible]
Weight recovered	12,022		
Yield	66.20%		
Tap nos. S1658			
Sow nos. 12877-12886 (10 sows)			
B/L no. 5038			

TK

YOUR BUSINESS

8

ERS, INC.

INVOICE NO. 4430

DATE: 11/5/88

SHIPPED TO:

CORP.
ND ROAD

33909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA 9663	NET

DESCRIPTION		UNIT PRICE	AMOUNT
23,760 lbs. Pot pads			
Weight received	23,760		
Non processible	------		
Weight processed	23,760	.075/lb.	$1[illegible]
Weight recovered	16,543		
Yield	69.63%		
Tap nos. 2593-2595			
Sow nos. 11311-11326 (16 sows)			
B/L no. RMO 9663			

YOUR BUSINESS

9

ERS, INC.

INVOICE NO. 4431

DATE: 11/5/88

SHIPPED TO:

CORP.
AND ROAD

33909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA 9672	NET

DESCRIPTION		UNIT PRICE	AMOUNT
22,080 lbs. Pot pads			
Weight received	22,080		
Non processible	------		
Weight processed	15,000	.10/lb.	$1[illegible]
Weight processed	7,080	.075/lb.	$ [illegible]
TOTAL INVOICE	------		$2,0[illegible]
Weight recovered	15,526		
Yield	70.32%		
Tsp nos. 2596/S1659			
Sow nos. 11327-11331/12887-12894 (13 sows)			
B/L no. RMO 9672			

10

...ERS, INC.

INVOICE NO. 4432

DATE: 11/6/88

SHIPPED TO:

...CORP.
...ND ROAD
...3909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA 57716-1	NET

DESCRIPTION		UNIT PRICE	AMOUNT
20,760 lbs. Pot pads			
Weight received	20,760		
Non processible	------		
Weight processed	9,000	.10/lb.	$ [illegible]
Weight processed	11,760	.075/lb.	$ [illegible]
TOTAL INVOICE	------		$1,7[illegible]
Weight recovered	15,788		
Yield	76.05%		
Tap nos. S1660/2597-2598			
Sow nos. 12895-12899/11332-11340 (14 sows)			
B/L no. 57116-1			

TK

...YOUR BUSINESS

ERS, INC.

11

INVOICE NO. 4433

DATE: 11/7/88

SHIPPED TO:

ORP.
AND ROAD

33909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA 44251	NET

DESCRIPTION		UNIT PRICE	AMOU
19,780 LBS. Pot pads			
Weight received	19,780		
Non processible	------		
Weight processed	6,500	.10/lb.	$ [illegible]
Weight processed	13,280	.075/lb.	$ [illegible]
Weight recovered	14,101		
Yield	71.29%		
TOTAL INVOICE			$1,646.00

Tap nos. S1661/2599-2601
Sow nos. 11341-11348/11345-11351 (13 sows)
B/L no. 44251

OUR BUSINESS

12

...ERS, INC.

INVOICE NO. 4434

DATE: 11/8/88

SHIPPED TO:

...RICA
...EPT.

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
AT 590414 BO	A/MOLD LINE	NET ON APPROVAL

DESCRIPTION		UNIT PRICE	AMOUNT
31,450 lbs. Spills and filters			
Weight received	31,450		
Non processible	------		
Weight processed	31,450	.09/lb.	$2[illegible]
Weight recovered	23,476		
Yield	74.64%		
Tap nos. 5588-5591/S1662			
Sow nos. 22082-22098 (23 sows) 12902-12907			
B/L no. C 4551 MSO 2661			

TK

...OUR BUSINESS

13

...ERS, INC.

INVOICE NO. 4435

DATE: 11/9/88

SHIPPED TO:

... CORP.

...522

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
SMP 22058	HIGH NICKLE	NET 11/10/88

DESCRIPTION	UNIT PRICE	AMO...
16,872 lbs. Aluminum sows @	.75/lb.	$1... .00

TAP#	#SOWS	WGT.
2603	3	3,150
2604	6	6,126
2605	7	7,596
TOTAL	16	16,872#

C

TK

...OUR BUSINESS...

14

...ERS, INC.

INVOICE NO. 4436

DATE: 11/9/88

SHIPPED TO:

...ICA
...PT.

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
AT 161248 CN	C-PAN	NET ON APPROVAL

DESCRIPTION		UNIT PRICE	AMOUNT
16,590 lbs. Pot pads			
Weight received	16,590		
Non processible	------		
Weight processed	16,590	.10/lb.	$1,[illegible]
Weight recovered	10,995		
Yield	66.27%		
Tap nos. S1663			
Sow nos. 12908-12917 (10 sows)			
B/L no. MSO 3620			

TK

...YOUR BUSINESS

15

ERS, INC.

INVOICE NO. 4437

DATE: 11/9/88

SHIPPED TO:

ICA
PT.

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
AT 161248 CN	E-PAN	NET ON APPROVAL

DESCRIPTION		UNIT PRICE	AMOU
16,490 lbs. Crushed material			
Weight received	16,490		
Non processible--iron, dust, etc.	-1,450		
Weight processed	15,040	.14/lb.	$2,
Weight recovered	6,611		
Yield	43.96%		
Tap nos. 2609			
Sow nos. 11386-11391 (6 sows)			
B/L no. MSO 3622			

TK

OUR BUSINESS

16

RS, INC.

INVOICE NO. 4438

DATE: 11/9/88

SHIPPED TO:

INC.

901

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	DWPP	NET 30 DAYS

DESCRIPTION		UNIT PRICE	AMOUNT
8,180 lbs. Solids and spills			
Weight received	8,180		
Non processible	-----		
Weight processed	8,180	.075/lb.	$61
Weight recovered	5,715		
Yield	69.86%		
Tap nos. 5592-5593			
Sow nos. 22099-22103 (5 sows)			
B/L no. 11107			

OUR BUSINESS

17

...ERS, INC.

INVOICE NO. 4439

DATE: 11/7/88

SHIPPED TO:

...G CORP.
...D
...23

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
SMP 22131		11/8/88

DESCRIPTION	UNIT PRICE	AMO...
...24,302 lbs. Aluminum sows @	.75/lbs.	$93...

TAP#	#SOWS	WGT.
2587	3	3,092
2588	7	8,041
2589	4	4,090
2590	7	7,373
2591	7	7,636
2592	4	4,047
2593	7	7,665
2594	3	3,144
2595	6	5,729
2596	5	5,521
2597	5	5,593
2598	4	4,076
2599	5	5,219
2600	3	3,335
2601	3	2,995
1656	7	8,221
1657	7	7,842
1658	10	12,022
1659	8	10,005
1660	5	6,119
[illegible]	2	2,552
		...,302#

TK

...R BUSINESS

18

LTERS, INC.

INVOICE NO. 4440

DATE: 11/10/83

SHIPPED TO:

CA
T.

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
AT 161248 CN	B-PAN	NET ON APPROVAL

DESCRIPTION		UNIT PRICE	AMOUNT
12,590 lbs. Pot pads			
Weight received	12,590		
Non processible	------		
Weight processed	12,590	.10/lb.	$1,[illegible]
Weight recovered	8,567		
Yield	68.05%		
Tap nos. S1664			
Sow nos. 12918-12925 (8 sows)			
B/L no. MSO 3614			

BUSINESS.

19

...ERS, INC.

INVOICE NO. 4441

DATE: 11/10/88

SHIPPED TO:

...RP.
... ROAD

...909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA 02632	NET

DESCRIPTION		UNIT PRICE	AMO...
20,340 lbs. Pot pads			
Weight received	20,340		
Non processible---copper, brass, iron	-2,550		
Weight processed	17,790	.075/lb.	$1[illegible].25
Weight recovered	12,707		
Yield	71.43%		
Tap nos. 2610-2612			
Sow nos. 11392-11403 (12 sows)			
B/L no. 02632			

...R BUSINESS

20

ERS, INC.

INVOICE NO. 4442

DATE: 11/11/88

SHIPPED TO:

ORP.
ND ROAD

3909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA 02634	NET

DESCRIPTION		UNIT PRICE	AMO
19,780 lbs. Pot pads			
Weight received	19,780		
Non processible	------		
Weight processed	19,780	.075/lb.	$1,
Weight recovered	13,356		
Yield	67.52%		
Tap nos. 2613-2614			
Sow nos. 11404-11415 (12 sows)			
B/L no. 02634			

UR BUSINESS

21

ERS, INC.

INVOICE NO. 4443

DATE: 11/11/88

SHIPPED TO:

CORP.
ND ROAD

3909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA 02633	NET

DESCRIPTION		UNIT PRICE	AMOUNT
19,600 lbs. Pot pads			
Weight received	19,600		
Non processible	------		
Weight processed	19,600	.075/lb.	$1[illegible]00
Weight recovered	14,140		
Yield	72.14%		
Tap nos. 5594-5595			
Sow nos. 22104-22117 (14 sows)			
B/L no. 02633			

OUR BUSINESS

22

ERS, INC.

INVOICE NO. 4444

DATE: 11/11/88

SHIPPED TO:

CORP.

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
SMP 22138	HIGH IRON	NET 11/14/88

DESCRIPTION		UNIT PRICE	AMO[illegible]
9,910 lbs. Aluminum sows	@	.62/lb.s	$6[illegible].20

TAP#	#SOWS	WGT.
2583	5	5,456
2584	4	4,454
TOTAL	9	9,910#

BUSINESS

23

[illegible]ERS, INC.

INVOICE NO. 4445

DATE: 11/11/88

SHIPPED TO:

[illegible] CORP.
[illegible]ND ROAD
[illegible]3909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA 02635	NET

DESCRIPTION		UNIT PRICE	AMOUNT
20,240 lbs. Pot pads			
Weight received	20,240		
Non processible	------		
Weight processed	12,000	.10/lb.	$1,[illegible]
Weight processed	8,240	.075/lb.	$ [illegible]
TOTAL INVOICE	------		$1,8[illegible]
Weight recovered	14,629		
Yield	72.28%		
Tap nos. S1665/2615			
Sow nos. 12926-12933/11416-11420 (13 sows)			
B/L no. 02635			

TC

[illegible]R BUSINESS

24

ERS, INC.

INVOICE NO. 4446

DATE: 11/11/88

SHIPPED TO:

CORP.
ND ROAD

3909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA 02631	NET

DESCRIPTION		UNIT PRICE	AMO[illegible]
24,760 lbs. Pot pads			
Weight received	24,760		
Non processible	------		
Weight processed	5,500	.10/lb.	$ [illegible]
Weight processed	19,260	.075/lb.	$1,[illegible]
TOTAL INVOICE	------		$1,99[illegible]
Weight recovered	19,090		
Yield	77.10%		

Tap nos. S1666/5596-5598
Sow nos. 12934-12936/22118-22132 (18 sows)
B/L no. 02631

C

TK

[illegible]R BUSINESS

25

...ERS, INC.

INVOICE NO. 4447

DATE: 11/12/88

SHIPPED TO:

...ORP.
...D ROAD
...3909

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SHIMA 02630	NET

DESCRIPTION		UNIT PRICE	AMOUNT
32,160 lbs. Pot pads			
Weight received	32,160		
Non processible	------		
Weight processed	32,160	.075/lb.	$2,[illegible]
Weight recovered	24,193		
Yield	75.23%		
Tap nos. 5599-5602			
Sow nos. 22133-22155 (23 sows)			
B/L no. 02630			

Tk

...OUR BUSINESS

26

...LTERS, INC.

INVOICE NO. 4449

DATE: 11/14/88

SHIPPED TO:

...3146

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
46316	MET	NET 30 DAYS

DESCRIPTION		UNIT PRICE	AMOU...
38,620 lbs. Dross and thermal chips			
Weight received	38,620		
Non processible	------		
Weight processed	38,620	.075/lb.	$2,[illegible]
Weight recovered	18,007		
Yield	46.63%		
Tap nos. 2619-2626			
Sow nos. 11433-11450 (18 sows)			
B/L no. 30887			

TK

...OUR BUSINESS

21

...TERS, INC.

INVOICE NO. 4450

DATE: 11/14/88

SHIPPED TO:

...ORP.

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
SMP 22058	HIGH NICKLE	NET 11/15/88

DESCRIPTION	UNIT PRICE	AMO...
12,848 lbs. Aluminum sows @	.75/lb.	$[illegible]

TAP#	#SOWS	WGT.
2616	6	6,618
2617	4	4,090
2618	2	2,140
TOTAL	12	12,848#

...UR BUSINESS

28

ERS, INC.

INVOICE NO. 4448

DATE: 11/14/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	A-1	NET ON RECEIPT

DESCRIPTION		UNIT PRICE	AMOU
35,245 lbs. Solids and dross			
Weight received	35,245		
Non processible	------		
Weight processed	35,245	.075/lb.	$2,
Weight recovered	18,917		
Yield	53.67%		
Tap nos. 5603-5606			
Sow nos. 22156-22174 (19 sows)			
B/L no. 5350/5338/5351			

Tk

BUSINESS

29

TERS, INC.

INVOICE NO. 4451

DATE: 11/15/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	SO. FLUX	NET ON RECEIPT

DESCRIPTION		UNIT PRICE	AMOUNT
16,650 lbs. Gross			
Weight received	16,650		
Non processible	-------		
Weight processed	16,650	.075/lb.	$1[illegible].75
Weight recovered	8,336		
Yield	50.07%		
Tap nos. 2625-2626			
Sow nos. 11455-11462 (8 sows)			
B/L no. NO #			

[illegible]OUR BUSINESS

30

...TERS, INC.

INVOICE NO. 4452

DATE: 11/15/88

...ICA
...PT.

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
AT 161248 CN	E-PAN	NET ON APPROVAL

DESCRIPTION		UNIT PRICE	AMOU...
..,370 lbs. Crushed material			
Weight received	23,370		
Non processible--~~iron~~, dust, etc.	1,550		
Weight processed	21,820	.14/lb.	$[illegible]
Weight recovered	9,292		
Yield	42.58%		
Tap nos. 2627-2628			
Sow nos. 11463-11471 (9 sows)			
B/L no. MSO 3625			

TK

...R BUSINESS

31

...TERS, INC.

INVOICE NO. 4453

DATE: 11/16/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
AT 590414 BO	MOLD LINE	NET ON APPROVAL

DESCRIPTION		UNIT PRICE	AMOU...
19,600 lbs. Mold line scrap			
Weight received	19,600		
Non processible	------		
Weight processed	19,600	.09/lb.	$1[illegible]
Weight recovered	14,438		
Yield	73.66%		
Tap nos. S1667-S1668			
Sow nos. 12937-12948 (12 sows)			
B/L no. C 4571 MSO 2661			

C

...UR BUSINESS

3

S, INC.

INVOICE NO. 4454

DATE: 11/16/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
45726	MEBG	NET 30 DAYS

DESCRIPTION		UNIT PRICE	AMO
,100 lbs. Dross and thermal chips			
Weight received	33,100		
Non processible	------		
Weight processed	33,100	.075/lb.	$2,
Weight recovered	16,167		
Yield	48.84%		
Tap nos. 5607-5611			
Sow nos. 22175-22190 (16 sows)			
B/L no. 32211			

TK

BUSINESS

33

[illegible]TERS, INC.

INVOICE NO. 4455

DATE: 11/16/88

SHIPPED TO:

[illegible]RP.

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
SMP 22147		NET 11/17/88

DESCRIPTION		UNIT PRICE	AMOUNT
[illegible]292 lbs. Aluminum sows	@	.85/lb.	$30[illegible]

[illegible]AP#	#SOWS	WGT.
[illegible]596	3	3,294
[illegible]601	6	6,410
[illegible]602	5	5,436
[illegible]610	2	1,969
2615	5	5,043
[illegible]594	8	7,969
[illegible]595	6	6,171
TOTAL	35	36,292#

DESCRIPTION		UNIT PRICE	AMOUNT
71,542 lbs. Aluminum sows	@	.78/lb.	$55,802.76

TAP#	#SOWS	WGT.
[illegible]666	3	3,751
[illegible]97	5	4,498
[illegible]	7	7,547
[illegible]	6	6,468
[illegible]	6	5,879
[illegible]	[illegible]	9,586
[illegible]	[illegible]	[illegible]229
[illegible]	[illegible]	[illegible]

6

[illegible]OICE DUE $86,650.96

[illegible]R BUSINESS

34

ERS, INC.

INVOICE NO. 4456

DATE: 11/17/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
AT 590414 BO	MOLD LINE	NET ON APPROVAL

DESCRIPTION		UNIT PRICE	AMOUNT
380 lbs. Mold line scrap			
Weight received	29,380		
Non processible	------		
Weight processed	29,380	.09/lb.	$2,
Weight recovered	22,477		
Yield	76.50%		
Tap nos. 2629-2631/S1669			
Sow nos. 11472-11487/12949-12953 (21sows)			
B/L no. C 4570 MSO 2661			

TR

BUSINESS

35

ERS, INC.

INVOICE NO. 4457

DATE:

11/17/88

SHIPPED TO:

P.

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
SMP 22058	HIGH NICKLE	NET 11/18/88

DESCRIPTION	UNIT PRICE	AMOUNT
,601 lbs. Aluminum sows @	.75/lb.	$[illegible]

TAP#	#SOWS	WGT.
5612	6	6,001
5613	7	7,600
TOTAL	13	13,601#

TK

BUSINESS

36

...ERS, INC.

INVOICE NO. 4458

DATE: 11/17/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
AT 590414 BO	MOLD LINE	NET ON APPROVAL

DESCRIPTION		UNIT PRICE	AMOUNT
...90 lbs. Mold line scrap			
Weight received	33,890		
Non processible	------		
Weight processed	33,890	.09/1b.	$[illegible]
Weight recovered	25,782		
Yield	76.07%		
Tap nos. 2632-2633/S1670			
Sow nos. 11488-11503/12954-12961 (24 sows)			
B/L no. C 3200 MSO 2661			
			TK

BUSINESS

3

...ERS, INC.

INVOICE NO. 4459

DATE: 11/18/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
AT 161248 CN	B-PAN	NET ON APPROVAL

DESCRIPTION		UNIT PRICE	AMOUNT
15,620 lbs. Pot pads			
Weight received	15,620		
Non processible	------		
Weight processed	15,620	.10/lb.	$1[illegible]
Weight recovered	9,883		
Yield %	63.27%		
Tap nos. S1671			
Sow nos. 12962-12969 (8 sows)			
B/L no. MSO 3618			

...R BUSINESS

38

TERS, INC.

INVOICE NO. 4460

DATE 11/19/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
45726	MEBG	NET 30 DAYS

DESCRIPTION		UNIT PRICE	AMOUNT
780 lbs. Dross and thermal chips			
Weight received	40,780		
Non processible			
Weight processed	40,780	.075/lb.	$3
Weight recovered	18,938		
Yield	46.43%		
Pour nos. 5614-5619			
Sow nos. 22204-22221 (18 sows)			
B/L no. 30760			

R BUSINESS

31

...ERS, INC.

INVOICE NO. 4461

DATE: 11/19/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	EMERSON	NET

DESCRIPTION		UNIT PRICE	AMOUNT
920 lbs. Dross in drums			
Weight received	29,920		
Non processible	-------		
Weight processed	29,920	.10/lb.	[illegible]
Weight recovered	15,366		
Yield	51.36%		
Tap nos. 2635-2638			
Sow nos. 11508-11521 (14 sows)			
B/L no. NO #			

TC

...BUSINESS

...ERS, INC.

INVOICE NO 4462

DATE: 11/20/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
AT 161248 CN	E-PAN	NET ON A...

DESCRIPTION		UNIT PRICE	AMOUNT
180 lbs. Crushed material			
Weight received	17,180		
Non processible---iron, dust, etc.	- 800		
Weight processed	16,380	.14/lb.	[illegible]
Weight recovered	8,461		
Yield	51.65%		
Tap nos. 2639-2641			
Sow nos. 11522-11529 (8 sows)			
B/L no. MSO 3626			

...R BUSINESS

ERS, INC.

INVOICE NO: 4463

DATE: 11/22/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
AT 161248 CN	B-BOX	NET ON

DESCRIPTION		UNIT PRICE	AMOUNT
130 lbs. Pot pads			
Weight received	48,130		
Non processible	------		
Weight processed	48,130	.10/lb.	$ [illegible]
Weight recovered	32,195		
Yield	66.89%		
Tap nos. S1672-S1675			
Sow nos. 12970-12996 (27 sows)			
B/L no. 04108 MSO 2259			

41

TK

BUSINESS

ERS, INC.

INVOICE NO. 4464

DATE 11/22/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
46448	INVENTORY TRANSFER	NET 12/22

DESCRIPTION		UNIT PRICE	AMOUNT
4,405 lbs. Aluminum sows	@	.90/lb.	[illegible]

TAG#	#SOWS	WGT.
2634	4	4,405#

TK

BUSINESS

43

ERS, INC.

INVOICE NO. 4465

DATE 11/22/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
SMP 22158	HIGH IRON	NET 1[illegible]

DESCRIPTION	UNIT PRICE	AMOUNT
[illegible]6 lbs. Aluminum sows @	.62/lb.	[illegible]

TAP#	#SOWS	WGT.
2606	2	2,318
2607	6	6,731
2608	4	4,107
TOTAL	12	13,156#

TK

BUSINESS

44

...ERS, INC.

INVOICE NO. 4466

DATE 11/22/88

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	
45726	MEBG	[illegible]

DESCRIPTION	UNIT PRICE	AMOUNT
...0 lbs. Dross and thermal chips		
Weight received 44,200		
Non processible ———		
Weight processed 44,200	.075/lb.	$3,[illegible]
Weight recovered 20,073		
Yield 45.41%		
Tap nos. 2642-2647		
Sow nos. 11530-11549 (20 sows)		
B/L no. 29011		

TK

BUSINESS

45

...ERS, INC.

INVOICE NO. 4467

DATE 11/23/08

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	
SMP 22156		NET [illegible]

DESCRIPTION

[illegible] lbs. Aluminum sows @ .78/lb.

TAP#	#SOWS	WGT.
[illegible]625	5	4,965
2626	3	3,371
TOTAL	8	8,336#

C

TR

46

…ERS, INC.

INVOICE NO. 4469

DATE 11/2…

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	[illegible]
46383		

DESCRIPTION	UNIT PRICE	AMOUNT
…ECTION IN POUNDAGE ON INVOICE #4424 …ED ON NOVEMBER 3, 1988 …ED AS 17,486 X .7025/lb. = 12,283.92 …ULD HAVE BEEN BILLED 17,846 X .7025/lb. = 12,536.82 … AMOUNT DUE FOR CORRECTED INVOICE		[illegible]

TK

…USINESS

47

ERS, INC.

INVOICE NO. 4470

DATE 11/[illegible]

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	
46419	MEKL	[illegible]

DESCRIPTION		UNIT PRICE	AMOUNT
[illegible]672 lbs. Dross in drums			
[illegible]ight received	38,672		
[illegible]n processible	------		
[illegible]ight processed	38,672	.075[illegible]	[illegible]
[illegible] recovered	21,837		
[illegible]	56.47[illegible]		
[illegible] 2652-2655			
[illegible] 11562-11581 (20 sows)			
[illegible] 273924			

TK

[illegible]USINESS

48

INVOICE NO. 4471

DATE [illegible]

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	[illegible]
AT 161248 CN	B-PAN	[illegible]

DESCRIPTION		UNIT PRICE	AMOUNT
...40 lbs. Pot pads			
...ight received	19,540		
...n processible			
...ight processed	19,540	.10/lb.	[illegible].00
...ight recovered	13,294		
...ield	68.03%		
... S1677			
... 13008-13018 (11 sows)			
... 2686-MSO			

...SINESS

41

S INC.

INVOICE No. 447

DATE:

SHIPPED TO

CUSTOMER P.O. NO.	IDENTIFICATION	
UT 161248 CN	D-PAN	

DESCRIPTION		UNIT PRICE	AMOUNT
lbs. Pot pads			
Weight received	10,120		
Non processible			
Weight processed	10,120	.10/lb	
Weight recovered	6,654		
Yield	65.75%		
nos. S1678			
nos. 13019-13024 (6 sows)			
no. MSO 3623			

TK

SHIPPED TO:

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
P.O. 3262	LORMET	NET

DESCRIPTION		UNIT PRICE	AMOUNT
lbs. Furnace bottoms			
received	37,420		
processible	-4,500		
processed	32,920	.11/lb.	
recovered	12,518		
id	38.020		
31676			
12997-13007 (11sows)			
NO #			

TK

SHIPPED TO

CUSTOMER P.O. NO.	IDENTIFICATION	
22058	HIGH NICKLE	

DESCRIPTION	UNIT PRICE	AMOUNT
lbs. Aluminum sows @	.75/lb	

	SOWS	WGT.
		2,104
		2,928
	5	5,900
	2	2,150
	12	13,082#

S, INC.

INVOICE NO.

DATE

SHIPPED TO

CUSTOMER P.O. NO.	IDENTIFICATION
161248 CN	E-PAN

DESCRIPTION

finished material

...ved	22,730
...ble--carbon, iron, dust	-1,040
...ssed	21,690
...ired	11,317
	54,024

...5621

...22232 (11 sows)

...2028

ilk

SHIPPED TO

CUSTOMER P.O. NO.	IDENTIFICATION	
161248 CN	D-PAN	

DESCRIPTION		UNIT PRICE	AMOUNT
Pot pads			
...ceived	16,250		
...ible			
...ocessed	16,250		
...ured	10,903		
	67.09%		
...033 (9 scwb)			

INC.

SHIPPED TO

CUSTOMER P.O. NO.	IDENTIFICATION	TERMS
VERBAL	A-1	

DESCRIPTION	UNIT PRICE	AMOUNT
Dross, solids, etc.		
received 35,9[illegible]		
[illegible]ible		
processed 35,9[illegible]		
recovered 17,[illegible]		
48,[illegible]		
[illegible] (17 [illegible])		

TMR

55

[illegible] INC. [illegible]

[illegible] Invoice No. 4[illegible]7[illegible]

[illegible] SHIPPED TO [illegible]

CUSTOMER'S P.O. NO.	IDENTIFICATION	TERMS
[illegible]0614 BO	SCALPER CHIPS	[illegible]

DESCRIPTION	UNIT PRICE	AMOUNT
[illegible] Scalper chips		
[illegible] received [illegible] 19,7[illegible]		
[illegible] ssible [illegible]		
[illegible] ocessed 19,7[illegible]		
[illegible] overed 13,9[illegible]		
70.4[illegible]		
[illegible]		

TK

[illegible], INC.

INVOICE NO. 44[illegible]

DATE

SHIPPED TO

CUSTOMER P.O. NO.	IDENTIFICATION	[illegible] TERMS
[illegible] 22149	HIGH [illegible]	

	DESCRIPTION	UNIT PRICE	AMOUNT
	[illegible]luminum sows @		
	[illegible] WGT.		
	3,196		
	5,346		
	3,191		
	3,[illegible]		
	[illegible]		

TK

INC.

INVOICE NO.

DATE

SHIPPED TO

CUSTOMER P.O. NO.	IDENTIFICATION	
	INVENTORY TRANSFER	

DESCRIPTION		UNIT PRICE	AMOUNT
...minum saws	8		

TK

58

DAT[illegible]

SHIPPED TO:

[illegible]	IDENTIFICATION	[illegible]
	[illegible]	

DESCRIPTION	UNIT PRICE	AMOUNT
[illegible] 4[illegible]		
3[illegible],[illegible]		
22,2[illegible]5		
[illegible]		

TK

54

Date Shipped	Salesman

Quantity

ASuminum Sows as follo

5475 lbs @

6366 lbs @

3651 lbs @

5222 lbs @

TOTAL DUE THIS IN

Item #

Date Shipped	Salesman

Quantity	
49,380 lbs Dross	

Weight received
Non processible
Weight processed
Weight recovered
Yield

Tap Nos. 2274-2277
Sow Nos. 8765-8806 (22 Sows)
B/L No. 21917

Item #

Date Shipped	Salesman	

Quantity

34,000 lbs Dross

Weight received
Non processible
Weight processed
Weight recovered
Yield

Tap Nos. 2278-2280
Sow Nos. 8807-8823
B/L No. 9075

Item

RE

Date Shipped	Salesman	Te...
		NET ...

Quantity

34,730 lbs Dross in Drums

Weight received
Non processible -90 drums-
Weight processed
Weight recovered
Yield

Tap NOs. 2281-2283
Sow Nos. 8824-8835 (12 Sows)

Item #

REORDER

63

Date Shipped	Salesman	Terms
		NET CA

Quantity	
18,955	lbs Solids
	Weight received Non processiblew Weight processed Weight recovered Yield
	Tap Nos. 2284-2285 Sow Nos. 8836-8847

561

Item # NV

REORDER ITEM

64

Date Shipped	Salesman	Terms
		NET 3

Quantity

24,480 lbs Dross & Drums

Weight received
Non processbile -6 Drums-
Weight processed
Weight recovered
Yield

Tap Nos. 2289-2290
Sow Nos. 8864-8875 (12 Sows)
B/L No. 3003

TAP#	#SOWS	WGT.
2289	7	8,599
2290	5	5,758

561

Item # NVR

REORDER ITEM #

65

Date Shipped	Salesman	Terms
		NET 45 DA[illegible]

Quantity	Desc[illegible]
22,960 lbs	Saw Fines & Chunks

Weight received
Non processible
Weight processed
Weight recovered
Yield

Tap Nos. 2291-2293
Sow Nos. 8876-8885 (10 Sows)
B/L no. 2783

TAP#	#SOWS	WGT.
2291	2	2420
2292	6	7616
2293	2	2464

561

66

Date Shipped	Salesman	Terms
		NET 45 DA[illegible]

Quantity	Descri[illegible]
31,020 lbs	Dross

Weight received
Non processible
Weight processed
Weight recovered
Yield

Tap Nos. 2294-2296
Sow Nos. 8886-8899 (14 Sows)
B/L No. 8745

TAP#	#SOWS	WGT.
2294	4	4,881
2295	6	7,603
2296	4	4,883

561

m # NVR11[illegible]

REORDER ITEM # NVR114T

67

Date Shipped	Salesman	Terms
		NET 45 DA

Quantity	Descr
31,520 lbs Chunks & Dross	

Weight received	3
Non processible	-
Weight processed	31
Weight recovered	50
Yield	50

561

Item # NVR114

REORDER ITEM # NVR114T

Date Shipped	Salesman	Terms
		NET 45 DAYS

Quantity	Description
31,520 lbs Chunks & Dross	

Weight received
Non processible
Weight processed
Weight recovered
Yield

Tap Nos. 2297-2298
Sow Nos. 8900-8912 (13 Sows)

TAP#	#SOWS	WGT.
2297	8	9762
2298	5	6190

561

69

Date Shipped	Salesman	Terms
		NET 5 DAYS

Quantity	Desc...
42,950	lbs aluminum sows

562

Date Shipped	Salesman	Terms
		DUE ON REC

Quantity	Descrip
17,338 lbs	Aluminum sows as follows:
	5,909 lbs
	4,821 lbs
	1,193 lbs
	1,083 lbs @
	4,332 lbs @
	Total due

562

Cover letter

Abstract approved by: Professor William J. Manning 10/7/2007

Potential reviewers:

	Dr. Andrew Meharg	a.meharg@abdn.ac.uk
	Dr. Lena Q. Ma	lqma@ufl.edu
	Dr. Mark P. Elless	ellessmp@aol.com
	Dr. C.Y. Lan	ls04@zsu.edu.cn
	Dr. Bala Rathinasabapathi	brath@mail.ifas.ufl.edu
Corresponding author:	Dr. C. Neal Stewart, Jr.	nealstewart@utk.edu

Aluminum accumulation in *Pteris cretica* and heavy metal uptake in vegetation growing on an abandoned aluminum smelter site in Knoxville, TN USA.

Jason M. Abercrombie[a], Melanie Stewart[b], Murali R. Rao[a], Michael E. Essington[b], and C. Neal Stewart, Jr. [a]

[a] Department of Plant Sciences, University of Tennessee, 2431 Joe Johnson Blvd., Knoxville, TN 37996-4561, USA

[b] Department of Biosystems Engineering and Soil Science, University of Tennessee, 2506 E.J. Chapman Dr., Knoxville, TN 37996-4531, USA

Corresponding author: C. Neal Stewart, Jr.

For correspondence: (phone: 865-974-6487; fax +1 865 946 1989; email nealstewart@utk.edu)
Permanent address: Department of Plant Sciences, University of Tennessee, 2431 Joe Johnson Blvd., Knoxville, TN 37996-4561, USA

"Capsule": *Pteris cretica* accumulated aluminum instead of arsenic in the presence of high concentrations of aluminum found in smelter slag.

Abstract

Smokey Mountain Smelters in Knoxville, Tennessee is an abandoned secondary aluminum smelter where smelter waste (slag) was dumped on site, potentially posing a threat to nearby human and ecosystem health. Metal concentrations in the slag (Al, As, Cd, Co, Cr, Cu, Ni, Pb, Se, Zn) were quantified by inductively-coupled plasma spectrophotometry (ICP) and characterized by x-ray diffraction (XRD). The highest metal concentrations observed were 223,000 mg kg^{-1} Al, 281 mg kg^{-1} As, 132 mg kg^{-1} Se, and 2910 mg kg^{-1} Cu. Metal uptake was quantified in leaves from plants growing on slag, as well as *Pteris cretica* plants employed to extract As from slag. Our data suggests that *P. cretica* accumulates Al in high concentrations, but not As, when grown in slag. Metal concentrations in vegetation growing on slag were lower than controls grown in

uncontaminated soil, suggesting low metal availability in slag or exclusion mechanisms in roots.

Keywords: Phytoremediation, Heavy metals, Aluminum uptake, *Pteris cretica*, Hyperaccumulator

1. Introduction

The smelting of heavy metals has resulted in extensive emissions of toxic metals into surrounding environmental media (Nriagu and Pacyna 1988). The environmental fate of emissions and waste generated during the smelting process is sometimes within close proximity to developed areas, thus posing a significant threat to human health. Smokey Mountain Smelters (SMS) is an abandoned secondary aluminum smelter in Knoxville, TN that was declared a Superfund site in 2001 due to massive piles of smelter slag and other unknown wastes over most of the ~12 hectare property. The site is located within a 1.6 km radius of numerous residential and commercial properties, wells, schools, churches, and directly adjacent to a large public housing complex (Figure 1). Because the slag material is exposed and uncovered, the surrounding community has no protection from pollution derived from groundwater leaching, stormwater runoff, and wind dispersal of the toxic metals.

Phytoremediation, or the use of plants to cleanup contaminated sites, may serve as an additional technology in the remediation of grossly polluted soils, such as the SMS site. Plants that can tolerate and thrive on metal-contaminated soils can prevent dispersal by creating a barrier to wind, but may also facilitate safer removal of contaminants via harvesting the above-ground shoot tissue, where metals may accumulate (Salt 1998). Surveys of native plants able to grow on metal-polluted land (e.g. slag spoils) provide more useful candidates for creating a site-specific, vegetative cap because the plants are well-suited to local conditions (Remon et al. 2005). Vegetative caps may serve to prevent erosion of the barren and exposed areas, while at the same time, initiate the processes of soil formation and vegetative succession (Munshower 1993). Plants that have evolved mechanisms of metal tolerance generally employ one of two main strategies; (1) uptake and accumulation in the vacuole or cell wall or (2) exclusion via organic acid exudates and suppression of root transporters (Baker 1987).

Mounting evidence has demonstrated the utility of *Pteris vittata* for the phytoextraction of arsenic from contaminated soils (Ma et al. 2001; Wei et al 2006a; Wei et al. 2006b; Wei et al. 2007; Wang et al. 2006; Wang et al. 2007). This species is desirable for field-scale phytoextraction of arsenic due to its high biomass and accumulation of > 2% of its dry mass as arsenic (Wang et al. 2002). Fayiga et al. (2004) investigated the effects of heavy metals on the growth and arsenic accumulation in *Pteris vittata* in a greenhouse study. They found that the fern was able to hyperaccumulate arsenic despite the presence of Cd, Ni, Pb, and Zn. We decided to use *Pteris cretica*, an arsenic-hyperaccumulating relative of *Pteris vittata*, in this investigation. The presence of high As concentrations found in the slag material at the SMS site and the observation that wild vegetation could thrive on the slag piles warranted a test of the hypothesis that *Pteris cretica* could grow in the slag and extract As from the media. A preliminary greenhouse study using slag from the smelter site demonstrated that *Pteris cretica* grew at a reduced rate compared to controls, but showed no other signs of phytotoxicity (Supplementary Figure 1.), thus providing the impetus for a field-scale trial of its performance at the SMS site.

The SMS site offers a unique opportunity for scientific investigation due to the various plant species that grow without symptoms of toxicity and predominate on the otherwise barren landscape of the heavy metal-laden property. Therefore, the objectives of this study were to (1) characterize and quantify the trace metals found in the slag piles, (2) evaluate the shoot tissue for heavy metal accumulation in plants that were found thriving on the piles, and (3) evaluate the capacity of arsenic phytoextraction in *Pteris cretica* when challenged with the mixed slag waste.

2. Materials and Methods

Study site: site history, hydrogeologic setting, and EPA site inspection summary

The Smokey Mountain Smelter site is located in Knoxville, TN (83°55'36.77" West longitude and 35°55'06.68" North latitude). The ~12 hectare property is partially wooded, but significantly barren and covered with large piles of unknown wastes thought to derive primarily from the secondary aluminum processing facility that operated onsite from 1979 until the close of operations sometime after May 1994. Prior to Smokey Mountain Smelters and the existence of environmental regulations, the site was home to Knoxville Fertilizer Company from at least 1922 until 1948, and subsequently associated with several agricultural chemical manufacturing companies until 1965 (Maupin 2005). The agricultural facility could have discharged wastes into settling ponds (TDHE 1983). No information is known concerning the regulatory status of the site prior to 1980.

During the years of SMS operation, SMS received numerous citations from the local division of air pollution control due to numerous complaints from local residents (KCDAPC 1985; KCDAPC 1989). The site historically had a strong ammonia odor and the waste was often burning (KCDAPC 1983). In addition to air pollution violations, the TN Division of Solid Waste Management issued a citation for operating a landfill without a permit and a geologic inspection of the site characterized the site as unsuitable for use as an industrial landfill (TDHE/DSWM 1983a; TDHE/DSWM 1983b). Materials that were incinerated in the smelters included by-products of primary aluminum production (i.e. aluminum dross, pot pads, pot bottoms, bath pads, and crushed material containing "non-processible" carbon, iron, cryolite (Na_3AlF_6), dust, etc. (Maupin 2005). Pot pads, pot bottoms, and bath pads are all generated inside of and in contact with spent potliners, which are listed hazardous wastes, designated as hazardous waste number K088 under the EPA Resource Conservation and Recovery Act (RCRA) (Maupin 2005). Maupin (2005) reported that between 1985 and 1992 SMS received large quantities of materials (oily scraper chips, furnace bottoms, magnetic separator accumulations, tabular balls, selee filters, south ingot furnace bottoms, mold line floor sweepings, can rec skim, and other miscellaneous materials derived from primary aluminum production) from a nearby primary Aluminum production facility in the city of Alcoa, TN. Large quantities of hazardous substances derived from the materials sent by the primary processing facility are known to still be present at the site (Maupin 2005).

The East Tennessee valley, in which the SMS site is situated, is oriented in a northeast-southwest direction as a result of folding and fracturing (TDC/DG 1956). The underlying geology of the SMS site is Middle Ordovician shale and characterized by extensive Karst development (TDC/DG 1956). Groundwater movement in such areas is restricted to largely interconnected fractures, thus potentially targeting approximately 2524 people that use groundwater in the 4 mi radius surrounding the SMS site (Maupin 2005).

Previous analytical results of groundwater samples from the site indicated the presence of antimony, arsenic, pentachlorophenol, dieldrin, and various toxic metals (except Cd), all exceeding the primary drinking water maximum contaminant levels as declared by the US EPA (Maupin 2005). This report also concluded that the onsite, unlined waste lagoon posed a serious threat to groundwater quality, considering the permeable subsurface. Similar conclusions were also reported for the vulnerability of local wetlands and downstream fisheries.

As a result of the aforementioned evidence, the TN Division of Remediation site inspection report suggested that the SMS site has potential to be placed on the National Priorities List for cleanup and recommended immediate remedial action. It is clear that trespassing occurs on the site by local children (Supplementary Figure 2); the adjacent housing project, Montgomery Village, currently houses hundreds of individuals and an elementary school is located approximately 1.6 kilometers away. For example, large gaps in the chain-link fencing on the side facing the adjacent public housing complex, well worn footpaths leading between the complex, and the predominance of graffiti within the dilapidated warehouse surrounding the rotary furnaces of the smelter (Supplementary Figure 2) raise obvious concerns for the health of local children.

Soil and plant sampling

During the month of May 2006, leaves were sampled from plants growing on smelter waste piles, but displaying no apparent symptoms of toxicity. Species selected for analysis were those found in multiple locations among the slag heaps, initially leading us to speculate that these species were employing some mechanisms of tolerance to high concentrations of several heavy metals. These species were: *Verbascum thapsus, Lirodendron tulipifera, Carduus nutans, Solidago canadensis, Ailanthus altissima*, *Parthenocissus quinquefolia, Platanus occidentalis,* and *Phytolacca americana.* Representative control samples for each species collected at the site were taken from an uncontaminated area adjacent to the Superfund site. Leaf samples were only collected for each species that appeared to best represent a mirror image of plant age, which was performed by on-site comparisons of leaf size and plant height. Each treatment (species) sampled consisted of ≥4 biological replicates.

Soil samples were taken with an auger to represent a depth ranging from 0-20 cm. All soil samples were air dried and sieved to < 2 mm prior to analysis. Each soil sampling was performed in triplicate at each plot from the *Pteris cretica* experiment, as well as the uncontaminated control plots. Due to the high clay content of the soil found in the nearby representative control soil samples (A, B, C; Figure 1), less compact soil with a higher organic content was selected for the *Pteris cretica* planting controls.

Pteris cretica experiment

Six 1 m^2 plots of waste soil were chosen to span the spatial range of the site for uptake experiments using *Pteris cretica* cv. Mayii. Within each plot, fifteen 5-month-old ferns were transplanted, spaced 20 cm apart, fertilized with 20-20-20 N:P:K Osmocote® fertilizer, and treated with a 3 kg application of lime. Shade cloth structures were employed randomly to three of the six plots, as well as one of the two control plots which were located adjacent to the contaminated area on uncontaminated soil. All plots were watered as needed with water from the on-site waste lagoon. After two months of growth in the field (June 1 – July 30th, 2006), above-ground biomass for each sample was harvested for metal analysis.

Sample preparation and chemical analysis

Soil, smelter slag, and plant tissue total metals (Al, As, Cd, Co, Cr, Cu, Mo, Ni, Pb, Se, Zn) were determined by a SPECTRO CIROS CCD EOP inductively coupled plasma spectrophotometer (ICP) with an AS400 autosampler (SPECTRO Analytical Instruments, Kleve, Germany). Three and a half grams were subjected to a 4 M nitric acid overnight reflux at 70 ºC according to Chang et al. (1984). One gram of leaf tissue from each plant analyzed was oven-dried at 60 ºC for 72 hrs and ashed in a muffle furnace at 450 ºC overnight. Ashed samples were digested with 10 ml of 1 N HNO_3, heated to dryness, then warmed to near boiling in 10 ml of HCl. Samples were brought to 50 ml volume with DDI H_20 and filtered using Whatman no. 42 paper prior to ICP analysis. To further characterize the mineralogy of the smelter slag, samples were subjected to x-ray diffraction (XRD) analysis using a D8 Advance with a K760 generator (Bruker AXS, Inc., Madison, WI). A simple fizz test was performed by adding a few drops of 10% HCl to confirm the presence of calcium carbonate in the slag material. Soil and slag pH was determined after a 1 hr shaking incubation of a 1:1 mixture of soil: 0.1 M $CaCl_2$.

Statistical analysis

Because all field data did not meet the assumptions for normality, a one-way Mann-Whitney *U* test was employed to evaluate the differences in mean metal uptake between slag-grown and control wild vegetation, as well as in comparisons of mean slag and control soil metal concentrations using JMP statistical software (SAS Inc., Cary, NC).

3. Results

3.1. Soil pH and heavy metal content of smelter slag and adjacent control soils

Table 1 summarizes the heavy metal content (Al, As, Cu, Cr, Cd, Co, Se, Ni, Pb, Zn) and pH of each designated plot (1-6) located within the smelter slag waste area, as well as the nearby uncontaminated soils (A-D), the locations of which are all indicated in Figure 1. Pb was not detected in any of the slag samples, but was present at low concentrations (>7 mg kg^{-1}) in control soils A-C (data not shown). XRD analysis of the slag material revealed the presence of polymorphs bayerite and gibbsite [Al(OH)3], spinel ($MgAl_2O_4$), calcite or $CaCO_3$, and calcium aluminum oxide ($Ca_3Al_2O_6$) (Supplemental Figure 3). Statistical comparisons of the mean metal content in slag and control soils reveal significant differences between slag material and control soils (Table 1). No significant differences in metal content were found to exist between the two depths assayed. Slag raw pH values ranged from 7.33 to 8.27, whereas raw pH values for the control soils ranged from 3.86 to 7.66 (Table 1). Metal content and pH for uncontaminated control soil employed in the *Pteris cretica* experiment is represented by control soil D (Table 1). Although relatively high in Al, As was not detected by ICP analysis of this soil. Additionally, Zn, Ni, Cu, Cr, and Co, were all relatively low in the fern control soil.

3.3 Heavy metal uptake in slag-grown Pteris cretica

Figure 2 illustrates the metal content in fronds of field-grown *P. cretica* plants harvested two months after planting. Despite the absence of As in the control soils used for this experiment, As uptake was observed to be restricted in the slag-grown ferns (Figure 2). However, Al was accumulated in high concentrations in the slag-grown ferns, ranging from 569 mg kg^{-1} to 4 380 mg kg^{-1}, and averaging 1 821 mg kg^{-1}. Slag-grown ferns also accumulated significantly higher amounts of Cu, Mo, Se, Zn, and Ni than were observed for control ferns.

3.2. Heavy metal uptake in slag-grown vegetation and bioaccumulation factors

A comparison of the heavy metal content in leaves of wild vegetation found growing on the slag heaps versus nearby uncontaminated control soils is illustrated in Figure 3. Surprisingly, restricted uptake of several species analyzed was indicated by significantly higher metal uptake in plants harvested offsite on uncontaminated soil compared to the slag-grown plants (Figure 3.), especially evident for the uptake of As, Se, Cu, and Co. One exception to this trend was demonstrated by the pioneering species *Verbascum thapsus*, accumulating the highest levels of aluminum uptake among slag-grown plants, as well as among controls (323 mg kg^{-1} and 137 mg kg^{-1}, respectively). Slag-grown *V. thapsus* also exhibited the highest Ni and As uptake, however all control plants exhibited higher As uptake compared to the slag-grown plants. *Carduus nutans* growing offsite accumulated the highest levels of As, Cr, Co, and Cd. *Phytolacca americana* contained the highest concentrations of Zn in leaf tissues harvested from plants growing in uncontaminated soil.

Bioconcentration factors (BCFs) (i.e. the ratio of metal concentrations in the shoot to those in the soil) indicate the efficiency at which plants extract metals from the soil. Slag-grown *P. cretica* exhibited the highest BCF values with respect to Al and Se (Figure 4). All plant species analyzed from uncontaminated soil had significantly higher BCFs for Al, As, Cu, Cr, Se, Ni, and Cd, with the exception of slag-grown *P. cretica* which exhibited much higher BCFs for Al, As, and Se. BCF for Zn in *P. cretica* grown in uncontaminated soil exceeded 50, dramatically higher than any other species. *Carduus nutans* grown in uncontaminated soil had the highest BCFs for As, Ni, and Cd.

4. Discussion

4.1 Heavy metal uptake and bioaccumulation factors in wild vegetation

Numerous investigators have surveyed wild plant populations growing on or nearby heavy metal-contaminated sites, generally with intentions of discovering species with novel remediation traits, such as heavy metal tolerance and accumulation. Del Rio et al. (2002) studied trace metal uptake in 99 wild plant species growing in an area contaminated from a spill of toxic pyretic sludge. These authors identified 11 plant species that demonstrated promising utility in the phytoremediation of Pb, Zn, Cu, Cd, and As due to their observed metal tolerance, accumulation, and high biomass. If phytoextraction is not a feasible means of remediation, then natural revegetation of a contaminated site can serve to stabilize the contamination by minimizing stormwater runoff and wind dispersal (Vangronsveld et al. 1995). In the current study, most plants exhibited significantly lower concentrations of trace elements in their leaves compared to control plants (Figure 2), thereby suggesting that either these plants were able to survive in the metalliferous medium via exclusion mechanisms or due to the neutral pH range of the slag and the abundance of aluminum (hydro)oxides, trace metal adsorption resulted in very low metal availability. Similar reports by Gonzalez and Gonzalez-Chavez (2006) suggest that most plants growing near mining wastes were employing exclusion mechanisms because metals did not accumulate in shoot tissues despite the high concentrations found in the soil. Despite the exclusion behavior found in those plants, two species, *Polygonum aviculare* and *Jatropha dioica* were reported to accumulate Zn at concentrations near the criteria for hyperaccumulation. Similarly, we report that slag-grown *Verbascum thapsus* was not only tolerant to the slag metal concentrations, but exhibited significantly higher accumulation of Ni and Al than those growing in uncontaminated soil (Figure 2). Regardless, the highest metal content observed in *V. thapsus* (462 mg kg^{-1}) was lower than sufficient for hyperaccumulator status. In a recent study of trace element (Cu, Fe, Mn, Ni, Pb, Zn) content in a close relative, *Verbascum olympicum*, Guleryuz et al. (2006) reported that heavy metal contents in different organs were highly correlated to heavy metal content found in the soil.

The BCF values for these species demonstrate that most of the wild species have no reasonable utility for employment in phytoextraction at the SMS site. McGrath and Zhao (2003) demonstrate that the two key components necessary for a plant to be of feasible utility in the phytoextraction of heavy metals are high biomass and high BCF (i.e. the metal concentrations in the above-ground biomass should exceed those found in the soil). Some of the species that grew on the slag exhibited substantial biomass (Supplementary Figure S2h). One obvious explanation for the low BCF values observed for slag-grown plants is the remarkably high metal concentrations found in the slag (Table 1). Even in the control plants that exhibited significantly higher BCFs than slag-grown plants, no wild species had a BCF close to 1. McGrath and Zhao (2003) present a useful model for selecting feasible candidates for phytoextraction. According to these authors, in order to reduce the metal concentration in the top 20 cm of topsoil by half, with a BCF of 1, even high biomass crops (20 t ha^{-1}) would require approximately 100 crop harvests.

4.2 Trace element uptake in Pteris cretica

Arsenic hyperaccumulation in members of the *Pteris* genus is well documented and the list of field-capable As-hyperaccumlating *Pteris* species and cultivars continues to grow as surveys of *Pteris* taxa found at As-contaminated sites are being conducted (Wei et al 2006; Wei et al. 2007; Wang et al. 2006; Wang et al. 2007). We selected *P. cretica* cv. Mayii because of its proven field-scale and hydroponic performance in As hyperaccumulation (Wei et al. 2006; Poynton et al. 2004; Fayiga et al. 2005). We were primarily interested in whether the fern was capable of extracting the high concentrations of As found in the slag material. Interestingly, the fern accumulated high amounts of Al during the 8 weeks of growth in the slag waste.

The most common criteria for a plant to be considered a hyperaccumulator is that the shoot metal concentration must exceed 1.0% for Zn and Mn, 0.1% for Al, As, Se, Ni, Co, Cr, Cu, and Pb and 0.01% for Cd (Branquinho et al. 2007). In this study, *P. cretica* clearly met these criteria for Al, however the extremely high concentrations of Al found in the growth medium (slag) contributed to a low BCF value, thus negating a characterization of *P. cretica* as a hyperaccumulator of aluminum at this time. However, the interesting observation that *P. cretica* exhibited a BCF of over 50 for Zn uptake (Figure 4) warrants further investigation into the uptake dynamics of *P. cretica* under Zn-deficient conditions, as was observed in control soils used in the *P. cretica* experiment. These results are similar to those found by An et al. (2006) who reported Zn tolerance and accumulation in *Pteris vittata*. These authors demonstrated that *P. vittata* accumulated up to 737 mg kg^{-1} Zn in fronds in the field, but could also accumulate As under high Zn concentrations, suggesting that *P. vittata* could be useful in sites co-contaminated with Zn and As. We did not detect the presence of As in the uncontaminated soil used for the *P. cretica* control plants in this study, thus explaining the very low amount of As observed in these plants.

Although aluminum (hydro)oxides were the predominant minerals found in the SMS slag, these minerals are also ubiquitous in soils and affect the fate and transport of ionic pollutants (Cox and Ghosh, 1994). Cox and Ghosh (1994) demonstrated that the adsorption of As(V), $CH_3AsO(OH)_2$, and $(CH_3)_2AsOOH$ to amorphous $Al(OH)_3$, gibbsite, α-Al_2O_3, and γ-AlO_3 increased up to pH 7, but decreased sharply at higher pH values. Extractions to determine the bioavailability of As in the slag material were not performed. However, based upon the uptake measurements observed in slag-grown *P. cretica*, we believe that the arsenic is likely adsorbed to the aluminum oxides/hydroxides found to predominate in the slag, thereby making As unavailable for uptake. This phenomenon has recently been reported in a study that characterized arsenate adsorption on aluminum oxide and phyllosilicate mineral surfaces in smelter-impacted soils (Beaulieu et al. 2005). These authors suggested that As originally released from the smelter was oxidized, dissolved, and adsorbed onto soil minerals and that the mildly acidic pH conditions found in the soil allowed for stable sorption complexes, thus preventing significant As mobilization. It is known that As mobility in soils is affected by pH (Adriano 1986). A recent study of As mobility in sites impacted by As mining and smelting suggested that As is mobile at extreme pH values (<2 or >8), such as those observed in mine tailings and tailings-impacted alluvial soils, however all other soils exhibited very low As mobility (Krysiak and Karczewska, 2007). Our data only reflect the pH values found in the top 20 cm of the slag piles, however since some of the plots exhibited pH values near 8 and greater (Table 1; plot 4 and 5), pH and resulting absorptive capacities in deeper zones may differ from those at the slag surface, thereby potentially mobilizing Al-bound As species into the groundwater.

4.3 Aluminum tolerance and accumulation

Aluminum toxicity in acid soils is a global agricultural dilemna, therefore much attention has been given towards understanding Al tolerance in plants. Attempts to identify genes involved in Al tolerance have been made in studies of Arabidopsis, wheat, barley, and, rye (reviewed by Magalhaes 2006). A major mechanism of Al tolerance that has been elucidated in these species is associated with the chelation of Al via exudation of the organic acid malate from the root apex, thereby preventing Al uptake via exclusion (Magalhaes 2006).

Conversely, Al accumulation has been reported for 127 species within the Melastomataceae family in the Order Myrtales, however the mechanisms through which this occurs are unknown (Jansen et al. 2002). Al accumulators have also been reported for members of the Rubiaceae and it is believed that these plants may utilize Si for Al detoxification, as relatively high Si levels were also observed in these plants (Jansen et al.

2003). However, this finding has not been confirmed because the Si : Al mole ratio widely varied among species (Jansen et al. 2003). The Al uptake in *Pteris cretica* observed in this study certainly warrants follow-up investigation. Because of the high number of environmental variables found in a field-scale study such as this, more controlled experiments are needed, paying particular attention to effects of pH and nutrient availability on Al content in various tissues. However, high Al accumulation was observed for all six plots, spanning a wide spatial range at the study site, thereby suggesting that the ferns are able to employ some mechanisms of accumulation.

Our data suggest that for wild vegetation growing on slag, Al is excluded, possibly via exudation of organic acids (i.e. malate, citrate) similar to well-characterized Al tolerance mechanisms. It is known that the solubility of Al is significantly reduced at pH 5.0 and above (Reid et al. 1971). Additionally, elevated concentrations of cations (i.e. Ca^{2+}, Mg^{2+}) in the rhizosphere are known to ameliorate Al toxicity (Brady et al 1993; Kinraide et al 1992). XRD analyses have revealed the presence of spinel ($MgAl_2O_4$), calcite or $CaCO_3$, and calcium aluminum oxide ($Ca_3Al_2O_6$), indicating the presence of such cations, thereby leading us to speculate that despite the abundantly high concentrations of Al found in the slag, the effects of pH and abundance of Ca^{2+} and Mg^{2+} ions likely decrease the concentration of Al^{3+} ions and ameliorate the phytotoxicity of the slag Al.

5. Conclusions

Our discovery that aluminum accumulation occurs in *Pteris cretica* when challenged with slag containing high concentrations of other toxic metals and metalloids has prompted us to investigate this phenomenon under controlled experimental conditions. We are particularly interested in the dynamics of As and Al uptake in *P. cretica* in the context of their bioavailability. Also as a result of this study, we intend to characterize the capacity for *P. cretica* to accumulate Cu and Zn.

It would be unreasonable to employ phytoremediation to cleanup a site as grossly contaminated as the SMS site, however this study has provided new insights that extend beyond phytoextraction. The windborne dispersal of metals at the SMS site may be decreased by continued succession of the known tolerant ecotypes found growing directly on the slag material. Therefore, phytostabilization of the slag may serve as an interim measure in prevention of contaminant spread that precedes appropriate remediation of this potential danger to the local community.

Additionally, we have identified several plant species as candidates for further study that may contribute to our understanding of aluminum tolerance. Because Al toxicity is such a significant global agricultural problem, exploring the molecular mechanisms that play a role in the exclusion of Al in the species evaluated in this study is warranted.

Acknowledgements

This work was supported by a grant from the National Science Foundation (OII-0548751). We are very grateful to Burl Maupin and the Knoxville Division of Remediation, Renee Hoyes at the Tennessee Clean Water Network (Knoxville, TN), and Barry Salkin at Public Employees for Environmental Responsibility (Nashville, TN) for facilitating this study. We appreciate our collaborators at Edenspace Systems Corporation for their valuable cooperation, especially, Mark Elless, David Lee, and Bruce Ferguson. The authors are grateful to Dwayne Estes of the University of Tennessee herbarium for assistance with botanical determinations. We appreciate the help of Hong-Seok Moon and Brian Leckie for collection of slag to enable preliminary experiments.

References

Adriano, D.C., 1986. Trace elements in the terrestrial environment. Sringer-Verlag, New York.

An, Z.Z., Huang, Z.C., Lei, M., Liao, X.Y., Zheng, Y.M., and Chen, T.B., 2006. Zinc tolerance and accumulation in *Pteris vittata* L. and its potential for phytoremediation of Zn- and As-contaminated soil. Chemosphere 62, 796-802.

Baker, A., McGrath, S., Reeves, R., and Smith, J. 2000. Metal hyperaccumulator plants: a review of the ecology and physiology of a biochemical resource for phytoremediation of metal-polluted soils. In : Terry, N., Banuelos, G. (Eds.), Phytoremediation of contaminated soils and waters. Lewis Publishers, Boca Raton, FL, 85-107.

Beaulieu, B.T., and Savage, K.S., 2005. Arsenate adsorption structures on aluminum oxide and phyllosilicate mineral surfaces in smelter-impacted soils. Environmental Science and Technology 39, 3571-3579.

Brady, D.J., Edwards, D.G., Asher, C.J., Blamey, F.C.P., 1993. Calcium amelioration of aluminum toxicity effects on root hair development in soybean (*Glycine max* L.) Merr. New Phytologist 123(3), 531-538.

Branquinho, C., Serrano, H.C., Pinto, M.J., and Martins-Loucao, M.A., 2007. Revisiting the plant hyperaccumulation criteria to rare plants and earth abundant elements. Environmental Pollution 146, 437-443.

Cox, D.D., and Ghosh, M.M., 1994. Surface complexation of methylated arsenates by hydrous oxides. Water Research 28 (5), 1181-1188.

Del Rio, M., Font, R., Almela, C., Velez, D., Montoro, R., and De Haro Bailon, A., 2002. Heavy metals and arsenic uptake by wild vegetation in the Guadiamar river area after the toxic spill of the Aznalcollar mine. Journal of Biotechnology 98, 125-137.

Fayiga, A.O., Ma, L.Q., Cao, X., and Rathinasabapathi, B., 2004. Effects of heavy metals on growth and arsenic accumulation in the arsenic hyperaccumulator *Pteris vittata* L. Environmental Pollution 132, 289-296.

Fayiga, A.O., Ma, L.Q., Santos, J., Rathinasabapathi, B., Stamps, B., and Littell, R.C. 2005. Effects of arsenic species and concentrations on arsenic accumulation by different fern species in a hydroponic system. International Journal of Phytoremediation 7, 231-240.

Gonzalez, R.C., and Gonzalez-Chavez, M.C., 2006. Metal accumulation in wild plants surrounding mining wastes. Environmental Pollution 144, 84-92.

Guleryuz, G., Arslan, H., Izgi, B., and Gucer, S., 2006. Element content (Cu, Fe, Mn, Ni, Pb, and Zn) of the ruderal plant *Verbascum olympicum* Boiss. from East Mediterranean. Zeitschrift fur Naturforschung 61, 357-362.

Jansen, S., Watanabe, T., and Smets, E., 2002. Aluminium accumulation in leaves of 127 species in Melastomataceae, with comments on the order Myrtales. Annals of Botany (Lond) 90, 53-64.

Jansen, S., Watanabe, T., Dessein, S., Smets, E., and Robbrecht, E., 2003. A comparative study of metal levels in leaves of some Al-accumulating Rubiaceae. Annals of Botany (Lond) 91, 657-663.

Kinraide, T.B., Ryan, P.R., and Kochian, L.V., 1992. Interactive effects of Al, H, and other cations on root elongation considered in terms of cell-surface electrical potential. Plant Physiology 99, 1461-1468.

KCDAPC, 1983. Facility inspection report, David Witherspoon, Inc. – Witherspoon and Johnson Dump. Inspected by the Knox County Department of Air Pollution Control, December 5.

KCDAPC, 1985. David Witherspoon – Historical record, Knox County Department of Air Pollution Control.

KCDAPC, 1989. List of complaints, inspections, and departmental action: Knox County Department of Air Pollution Control, August 10.

Krysiak, A., and Karczewska, A., 2007. Arsenic extractability in soils in the areas of former arsenic mining and smelting, SW Poland. Science of the Total Environment 379, 190-200.

Magalhaes, J.V., 2006. Aluminum tolerance genes are conserved between monocots and dicots. Proceedings of the National Academeies of Science U S A 103, 9749-9750.

Maupin, B.H., 2005. Expanded site inspection report: Smokey Mountain Smelters, Knox County, TN 37920, TN Division of Remediation site # 47-559, U.S. EPA ID # TN0002318277 Vol. 1.

McGrath, S.P., and Zhao, F.J., 2003. Phytoextraction of metals and metalloids from contaminated soils. Current Opinion in Biotechnology 14, 277-282.

Munshower, F.F., 1993. Practical handbook of disturbed land revegetation. Lewis Publishers, Boca Ratton, FL.

Nriagu, J.O., and Pacyna, J.M., 1988. Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature 333, 134-139.

Poynton, C.Y., Huang, J.W., Blaylock, M.J., Kochian, L.V., and Elless, M.P., 2004. Mechanisms of arsenic hyperaccumulation in Pteris species: root As influx and translocation. Planta 219, 1080-1088.

Reid, D.A., Fleming, A.I., and Foy, C.D., 1971. A method for determining aluminum response of barley in nutrient solution in comparison to response in Al-toxic soil. Agronomy Journal 63, 600-603.

Remon, E., Bouchardon, J.L., Cornier, B., Guy, B., Leclerc, J.C., and Faure, O., 2005. Soil characteristics, heavy metal availability and vegetation recovery at a former metallurgical landfill: Implications in risk assessment and site restoration. Environmental Pollution 137, 316-323.

Salt, D.E., Smith, R.D., and Raskin, I., 1998. Phytoremediation. Annual Review of Plant Physiology and Plant Molecular Biology 49, 643-668.

TDC/Division of Geology (DG), 1956. Groundwater Resources of East Tennessee., State of Tennessee, Department of Conservation, Division of Geology. Bulletin 58, Part 1., 6-9, 12, 43-4, 245-68.

TDHE/DSWM, 1983a. Letter to D. Johnson (Smokey Mountain Smelters), RE: Geologic evaluation of proposed industrial storage yard and landfill, November 18.

TDHE/DSWM, 1983b. Report of geologic investigation, by G. Pruitt (DSWM), November 4.

Vangronsveld, J., Van Assche, F., and Clijsters, H., 1995. Reclamation of a bare industrial area contaminated by non-ferrous metals: in situ metal immobilization and revegetation. Environmental Pollution 87, 51-59.

Wang, J., Zhao, F.J., Meharg, A.A., Raab, A., Feldmann, J., and McGrath, S.P., 2002.

Mechanisms of arsenic hyperaccumulation in *Pteris vittata*. Uptake kinetics, interactions with phosphate, and arsenic speciation. Plant Physiology 130, 1552-1561.

Wang, H.B., Ye, Z.H., Shu, W.S., Li, W.C., Wong, M.H., and Lan, C.Y., 2006. Arsenic uptake and accumulation in fern species growing at arsenic-contaminated sites of southern China: field surveys. International Journal of Phytoremediation 8, 1-11.

Wang, H.B., Wong, M.H., Lan, C.Y., Baker, A.J., Qin, Y.R., Shu, W.S. et al., 2007. Uptake and accumulation of arsenic by 11 Pteris taxa from southern China. Environmental Pollution 145, 225-233.

Wei, C.Y., and Chen, T.B., 2006. Arsenic accumulation by two brake ferns growing on an arsenic mine and their potential in phytoremediation. Chemosphere 63, 1048-1053.

Wei, C.Y., Sun, X., Wang, C., and Wang, W.Y., 2006. Factors influencing arsenic accumulation by *Pteris vittata*: a comparative field study at two sites. Environmental Pollution 141, 488-493.

Wei, C.Y., Wang, C., Sun, X., and Wang, W.Y., 2007. Arsenic accumulation by ferns: a field survey in southern China. Environmental Geochemistry and Health 29, 169-177.

Figure legends

Figure 1. Satellite image of the abandoned Smokey Mountain Smelter site in South Knoxville, TN, USA (Image from Google™ Earth). The large building on the property houses two rotary furnaces and an incinerator. Slag from the smelting process now exists in piles over much of the property. Numbers 1-6 and respective black spots designate plots of *Pteris cretica* plantings and slag sampling. The white line outlines the waste lagoon. Letters A-D indicate approximate locations of uncontaminated soil sampling. The right side of the image shows the adjacent public housing project.

Figure 2. Trace element accumulation (mg kg^{-1}) in *Pteris cretica* grown on slag piles at the SMS site for 8 weeks. Black bars indicate plants grown on slag piles and grey bars refer to plants grown in uncontaminated control soil D (Table 1).

Figure 3. Trace element accumulation (mg kg^{-1}) in wild vegetation found growing on slag piles at the SMS site. Species represented are *Verbascum thapsus, Lirodendron tulipifera, Carduus nutans, Solidago canadensis, Ailanthus altissima*, *Parthenocissus quinquefolia, Platanus occidentalis,* and *Phytolacca americana.* Black bars indicate plants grown on slag

piles and grey bars refer to plants grown in uncontaminated control soils represented by controls A, B, and C (Table 1).

Figure 4. Bioconcentration factors (BCF) of trace elements in slag-grown wild vegetation and *Pteris cretica*. Species represented are *Verbascum thapsus, Lirodendron tulipifera, Carduus nutans, Solidago canadensis, Ailanthus altissima*, *Parthenocissus quinquefolia, Platanus occidentalis, Phytolacca americana* and *Pteris cretica.* Black bars indicate plants grown on slag piles and grey bars refer to plants grown in uncontaminated control soils. Control BCFs for wild vegetation were calculated from control soils A, B, and C, whereas BCFs for *Pteris cretica* controls were derived from control soil D.

Tables

Table 1
Heavy metal concentrations (mg kg^{-1}) in smelter slag (plots 1-6) and uncontaminated control soil (A-C) expressed as mean ± sd. *P* values represent one-way Mann-Whitney *U* test comparisons of slag and control means.

plot	depth (cm)	pH	Al	As	Zn	Se	Ni	Cu	Cr	Co	Cd
1	1-10	7.65	178 186.1 ± 12 944.9	196.1 ± 14.0	318.4 ± 128.8	19.7 ± 1.2	333.3 ± 105.5	924.8 ± 378.4	47.8 ± 4.4	6.6 ± 0.8	15.2 ± 1.0
	10-20	7.60	169 653.2 ± 19 257.2	182.3 ± 20.0	457.2 ± 196.8	21.8 ± 4.2	239.0 ± 118.5	790.8 ± 398.4	49.2 ± 11.8	5.8 ± 0.3	14.2 ± 1.4
2	1-10	7.64	203 842.6 ± 5 872.1	219.6 ± 5.7	610.8 ± 298.2	25.2 ± 6.8	1 196.5 ± 648.7	999.0 ± 775.0	67.6 ± 23.0	7.9 ± 2.9	17.0 ± 0.7
	10-20	7.58	189 689.3 ± 29 481.8	204.0 ± 27.3	233.4 ± 118.0	17.9 ± 9.2	1 750.4 ± 223.7	2 082.5 ± 208.4	42.0 ± 25.8	7.7 ± 1.5	16.0 ± 2.3
3	1-10	7.42	181 230.7 ± 12 607.9	202.6 ± 12.4	879.2 ± 85.0	53.4 ± 2.9	318.0 ± 22.2	1 479.3 ± 53.3	111.4 ± 8.6	9.0 ± 0.5	17.1 ± 0.5
	10-20	7.62	168 019.9 ± 13 837.1	185.7 ± 13.7	767.0 ± 159.2	49.1 ± 3.5	309.1 ± 30.0	1 873.5 ± 469.7	103.3 ± 8.5	8.1 ± 1.1	15.8 ± 0.8
4	1-10	7.78	201 143.5 ± 22 991.2	212.2 ± 23.2	160.0 ± 25.0	111.1 ± 16.6	82.9 ± 24.1	685.1 ± 169.9	309.1 ± 57.0	4.0 ± 0.7	15.9 ± 2.5
	10-20	8.13	185 884.5 ± 13 539.8	189.7 ± 15.8	105.3 ± 12.9	116.3 ± 15.6	61.2 ± 15.6	500.4 ± 32.8	345.9 ± 41.1	4.2 ± 0.8	16.5 ± 1.4
5	1-10	7.55	209 260.1 ± 17 348.7	209.1 ± 6.2	255.6 ± 80.2	19.4 ± 3.4	531.8 ± 18.4	827.5 ± 124.4	44.1 ± 4.9	6.9 ± 0.3	18.3 ± 0.5
	10-20	7.99	198 448.5 ± 5 799.2	207.5 ± 9.1	436.1 ± 237.6	36.0 ± 15.9	324.8 ± 121.6	871.8 ± 195.5	81.9 ± 36.8	6.6 ± 0.8	18.2 ± 0.8
6	1-10	7.60	210 222.7 ± 8 885.6	221.1 ± 11.8	676.9 ± 156.4	34.4 ± 7.7	882.6 ± 473.3	1 639.5 ± 319.3	82.8 ± 22.7	9.2 ± 0.9	19.8 ± 1.0
	10-20	7.78	222 957.6 ± 16 889.1	230.3 ± 26.2	719.2 ± 255.0	27.0 ± 8.6	691.5 ± 672.5	1 440.8 ± 628.7	65.2 ± 22.3	8.3 ± 2.8	20.5 ± 2.3
A	1-10	6.46	19 918.9 ± 109.9	41.4 ± 2.0	4 645.4 ± 219.2	nd	24.6 ± 0.9	990.8 ± 43.8	20.9 ± 0.9	30.1 ± 1.3	13.0 ± 0.6
	10-20	7.43	23 876.4 ± 2 374.4	43.0 ± 4.9	3 284.5 ± 509.2	2.5 ± 0.7	28.3 ± 3.2	742.6 ± 116.7	23.5 ± 3.1	25.9 ± 2.4	11.3 ± 1.1
B	1-10	6.73	39 607.4 ± 694.4	53.2 ± 1.2	289.6 ± 64.3	16.4 ± 2.1	44.0 ± 0.6	187.5 ± 16.4	32.5 ± 0.4	18.5 ± 1.4	8.6 ± 0.4
	10-20	6.44	13 686.5 ± 23 100.7	58.7 ± 5.6	267.5 ± 44.3	19.8 ± 0.6	53.7 ± 6.5	215.0 ± 37.4	35.3 ± 2.6	22.4 ± 0.9	9.4 ± 0.8
C	1-10	6.36	358.6 ± 12.5	36.1 ± 0.7	147.5 ± 35.2	79.1 ± 2.7	39.8 ± 3.0	57.3 ± 20.7	29.6 ± 0.8	34.0 ± 1.8	0.8 ± 0.0
	10-20	6.26	408.0 ± 51.6	nd	120.3 ± 12.0	77.3 ± 1.6	38.5 ± 1.0	42.9 ± 5.7	29.6 ± 1.1	32.3 ± 0.8	0.8 ± 0.0
D	1-10	5.65	41 761.7 ± 252.6	nd ±	0.7 ± 0.0	nd	5.5 ± 0.1	2.7 ± 0.1	0.5 ± 0.0	0.6 ± 0.1	0.8 ± 0.0
	10-20	5.80	29 295.4 ± 3 083.7	nd ±	0.7 ± 0.1	nd	5.9 ± 0.6	2.8 ± 0.4	0.5 ± 0.1	0.5 ± 0.0	0.9 ± 0.1
P			***	***	***	***	***	***	***	***	***

P<0.01,P<0.001,*** P<0.0001*


D
C
B
A
6
5
4
3
2
1
© 2007 Europa Technologies
© 2007 Tele Atlas
©2006 Google™
Pointer 35°55'06.80" N 83°55'32.98" W elev 905 ft
Streaming |||||||||| 100%
Eye alt 1945 ft

Figure 1.

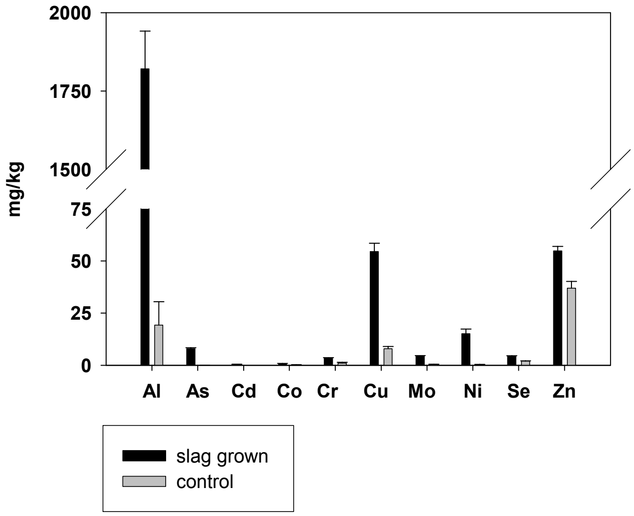

2000
1750
1500
75
50
25
0
mg/kg
Al
As
Cd
Co
Cr
Cu
Mo
Ni
Se
Zn
slag grown
control

Figure 2.

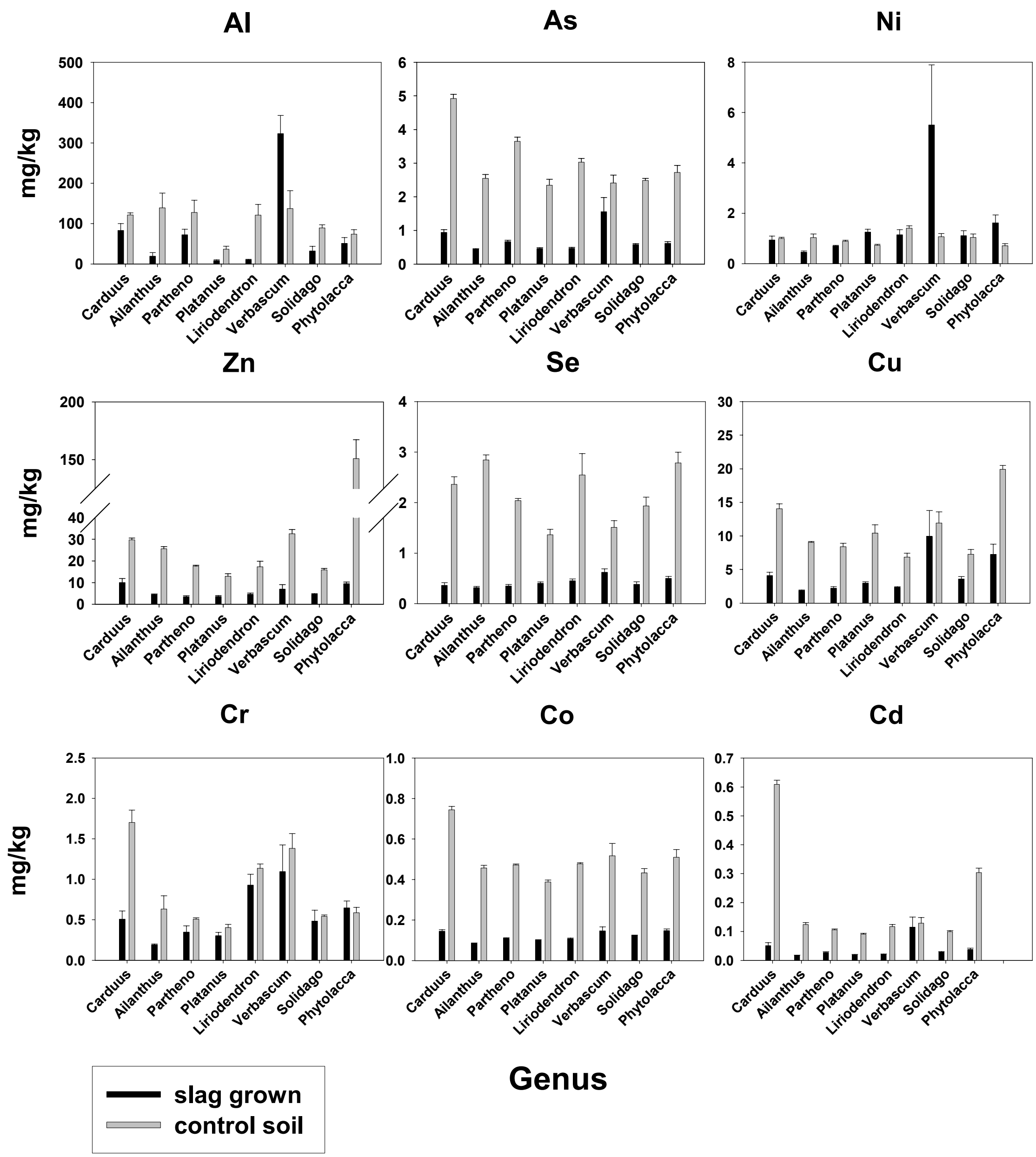
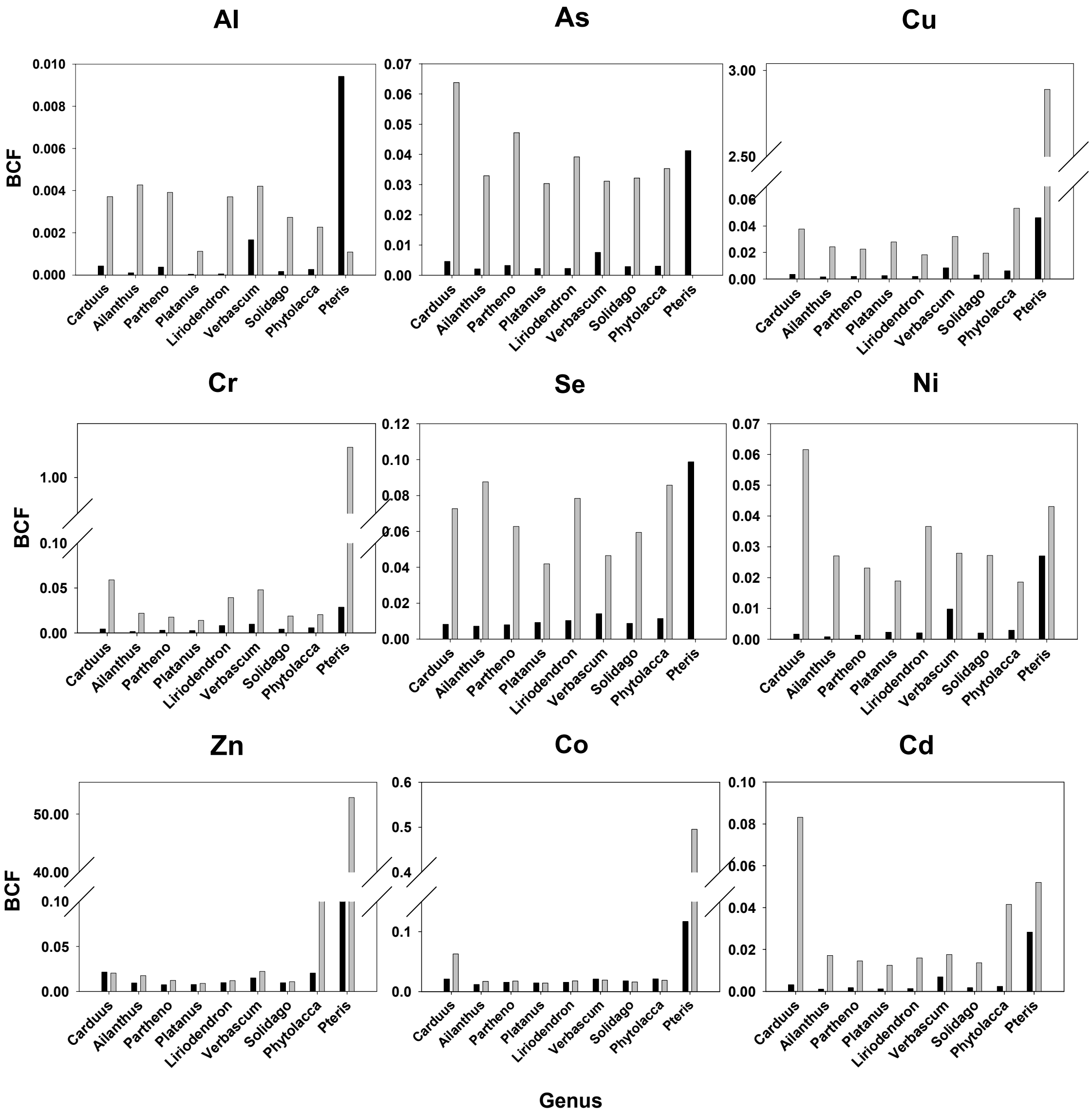

Al
As
Ni
Zn
Se
Cu
Cr
Co
Cd
mg/kg
Carduus
Ailanthus
Partheno
Platanus
Liriodendron
Verbascum
Solidago
Phytolacca
Genus
slag grown
control soil

Figure 3.



Al
As
Cu
Cr
Se
Ni
Zn
Co
Cd
BCF
Carduus
Ailanthus
Partheno
Platanus
Liriodendron
Verbascum
Solidago
Phytolacca
Pteris
Genus

Figure 4.

Experimental Rationale : Greenhouse-grown *Pteris cretica* survives 2 months of growth in aluminum-rich smelter slag.

Control soil **Slag-grown**

A **B**

Figure S2a. The Smokey Mountain Smelter building and surrounding slag piles. A, a picture taken during Winter 2005. B, a picture taken during Summer 2007. Notice the seasonal difference in vegetation but also, the degradation of the roof of the building in just two years time.

A **B**

Figure S2b. Inside the old building of the SMS site. A, picture taken inside the building in 2005. B, picture taken inside the building in 2007. This illustrates the dilapidated nature of the structure and the rapid degradation of the metal siding on the building. There are also enormous piles of slag waste inside the building, as seen here.

Figure S2c. Two rotary furnaces housed inside the building at the SMS site.

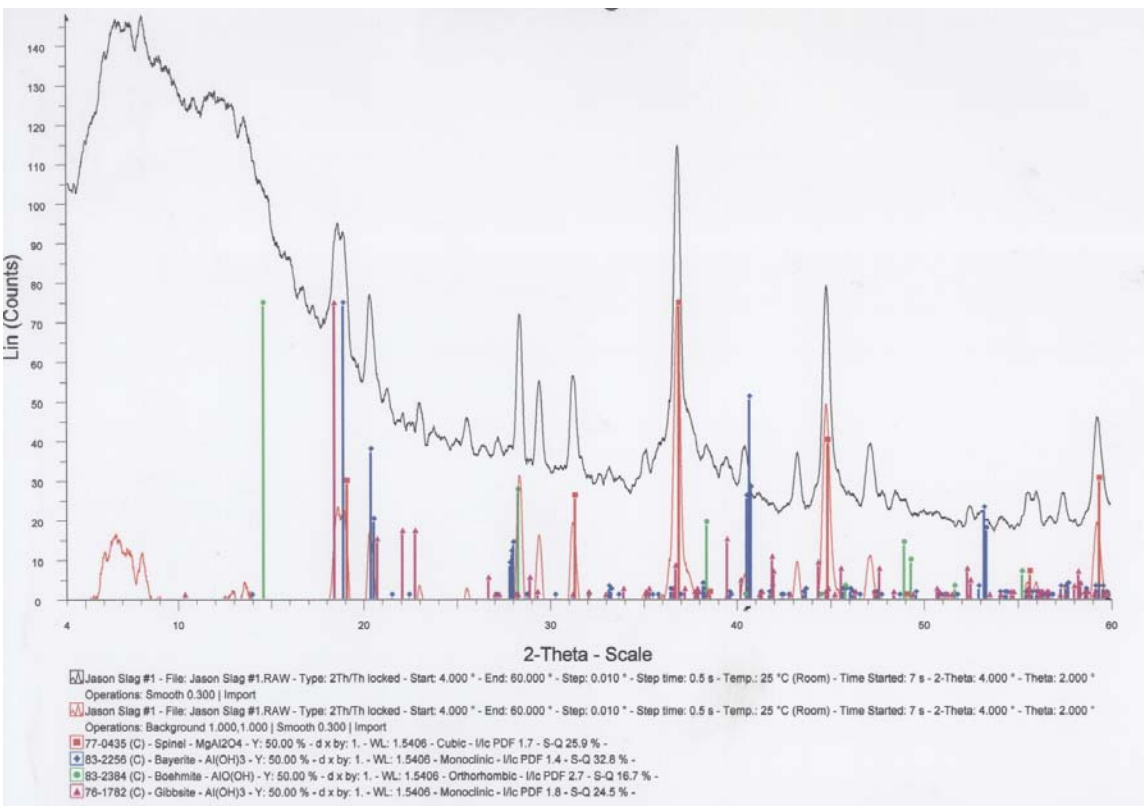
Figure S2d. Animal tracks are often seen in the slag dust. These are raccoon tracks, however, the far left of the image is the track of a dog. Local pets would have no problem accessing this site if left unattended.

Figure S2e. Graffiti from local children abounds within the building, illustrating that the property is visited by local trespassing children.

Figure S2f. A large gap in the fencing between the SMS site and the adjacent housing project facilitates trespassing by curious children. Well worn footpaths also indicate the presence of tresspassers from this opening.

Figure S2g. Incinerator located inside the SMS building. This entire side of the building has fallen down.

Figure S2h. From right to left, *Liriodenron tulipifera, Phytolacca Americana, and Platanus occidentalis* growing in the slag piles during the Summer of 2007.



Supplementary Figure 3
X-ray diffraction analysis of the smelter slag material reveals the presence of bayerite, gibbsite, spinel, calcite or calcium carbonate, and calcium aluminum oxide.